Beauty-related measurements at RHIC

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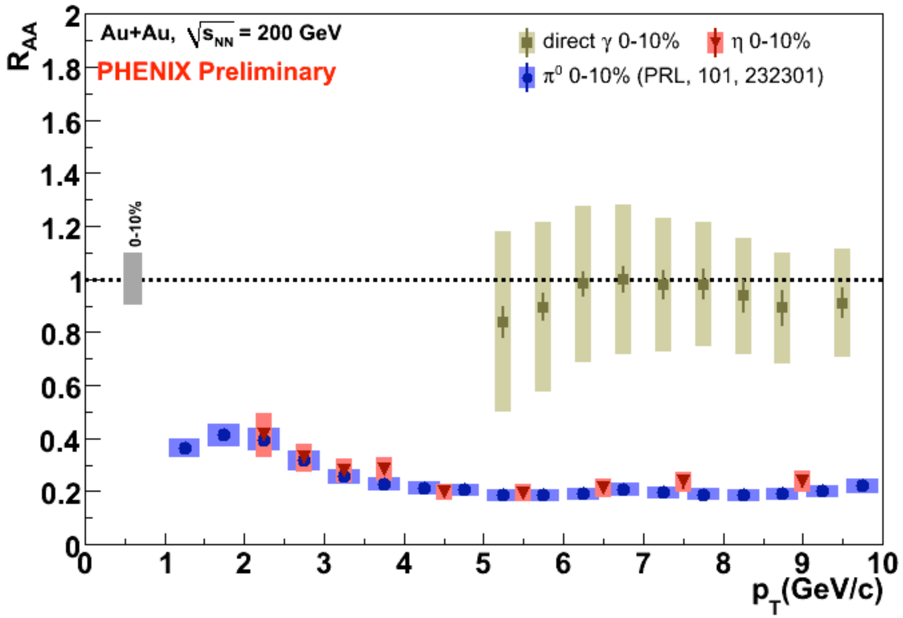
Motivation



- Observe :
  - Mesons (π^0, η, ρ, ω, ϕ, K) are suppressed,
  - Direct γ are a reference
- … suggest quark energy loss in the medium.

- What do happens to heavy quarks ?
  - They are heavier… are they less sensitive to the medium at RHIC ?
  - Or is the medium density high enough for them to be suppressed ?
- A fraction of them will form quarkonia, what happens to those ?
- What do data tell ?

Challenge and Outline

Introduction, some words of caution:

- *Bottom and bottomonia are hard rare probes.*
- *Triggering on them is challenging.*
- *Although at RHIC they are produced scarcely, we already observe first hints of their production.*

Outline:

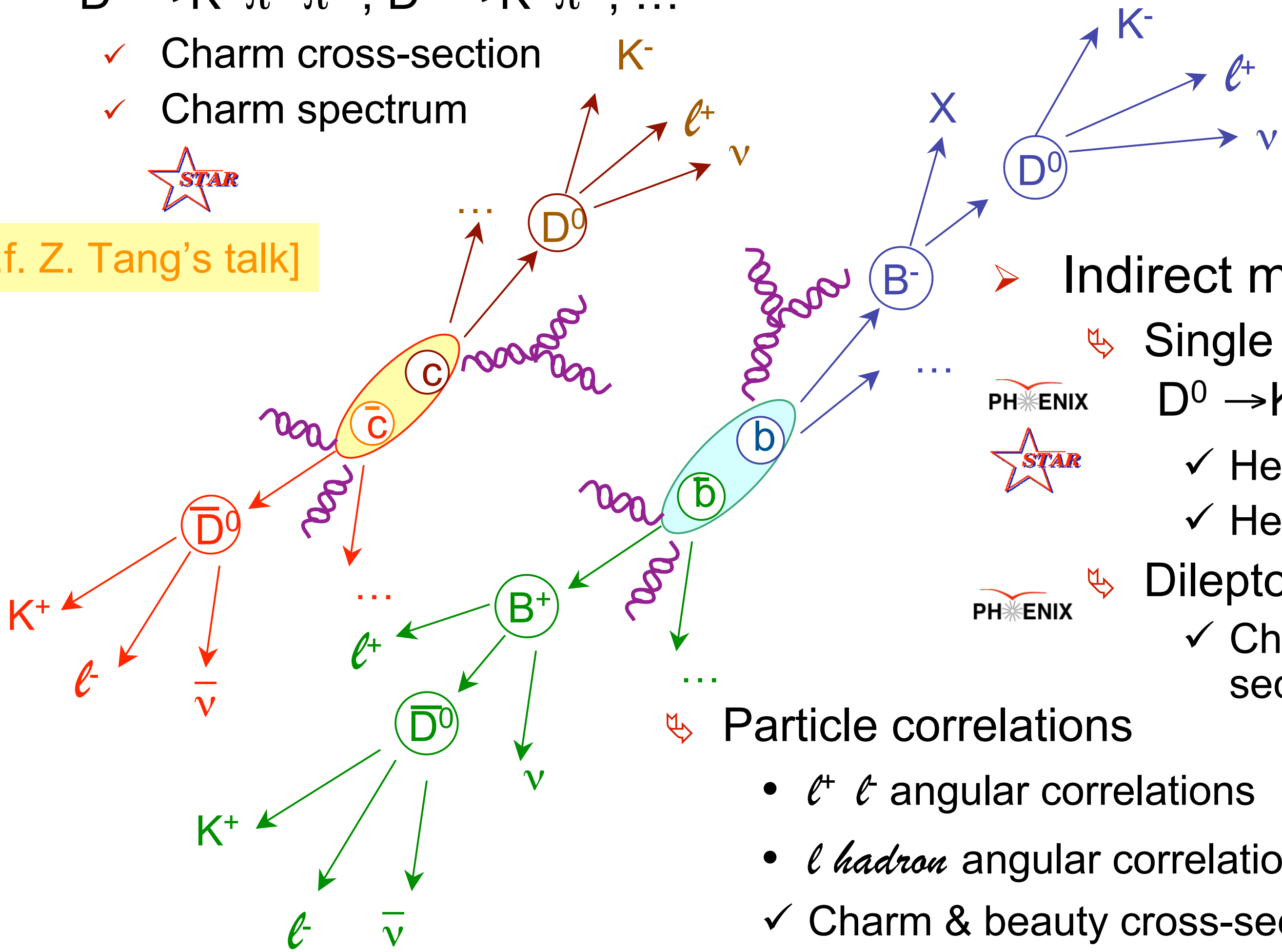
- **Beauty**-related measurements
  - Single non-photonic spectra
  - B/(B+D) separation via particle correlations
  - Hints of their behaviour in heavy ion collisions
- First Υ measurements at RHIC, p-p, dAu & Au-Au


The Beauty…

Heavy quark collection menu at RHIC

- Direct reconstruction:
  $D^+ \to K^- \pi^+ \pi^+$; $D^0 \to K^- \pi^+$; …
  - ✓ Charm cross-section
  - ✓ Charm spectrum

[c.f. Z. Tang's talk]



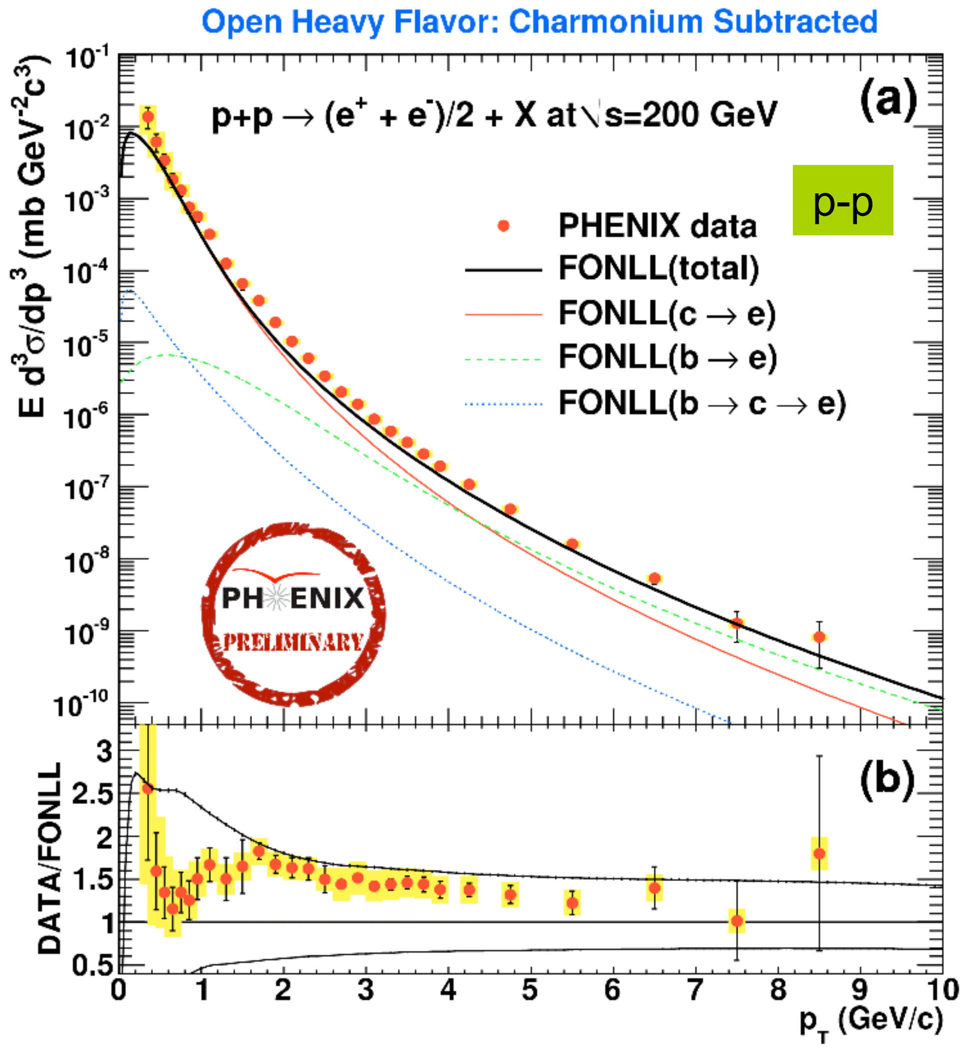
- Indirect measurements:
  - Single lepton
    $D^0 \to K^- \ell^+ \nu$; $B^- \to D^0$ …
    - ✓ Heavy quark cross-section
    - ✓ Heavy quark spectrum
  - Dilepton invariant mass
    - ✓ Charm & beauty cross-sections
  - Particle correlations
    - $\ell^+ \ell^-$ angular correlations
    - ℓ hadron angular correlations
    - ✓ Charm & beauty cross-sections
    - ✓ Charm & beauty spectra

- Waiting for B-tagging via decay vertex reconstruction…

Open heavy flavor p_t spectra

- Total heavy flavor:
  - Single inclusive $e^{\pm}$ spectra
  - Subtract cocktail of known sources: π^0, η, γ conversion…
  - Cross-check inserting an additional converter
- Open heavy flavor by subtracting J/Ψ, Υ, Drell-Yan. Negligible contribution at low p_t, but up to ~16% at higher p_t.
- Studies done for p-p & Au-Au.

- Agreement with FONLL within current uncertainties.
- Charm dominates at low pt
  $\sigma(c\bar{c})$ = 567 ± 47 (stat) ± 224 (sys) μb;
- This does not allow to measure the bottom contribution.



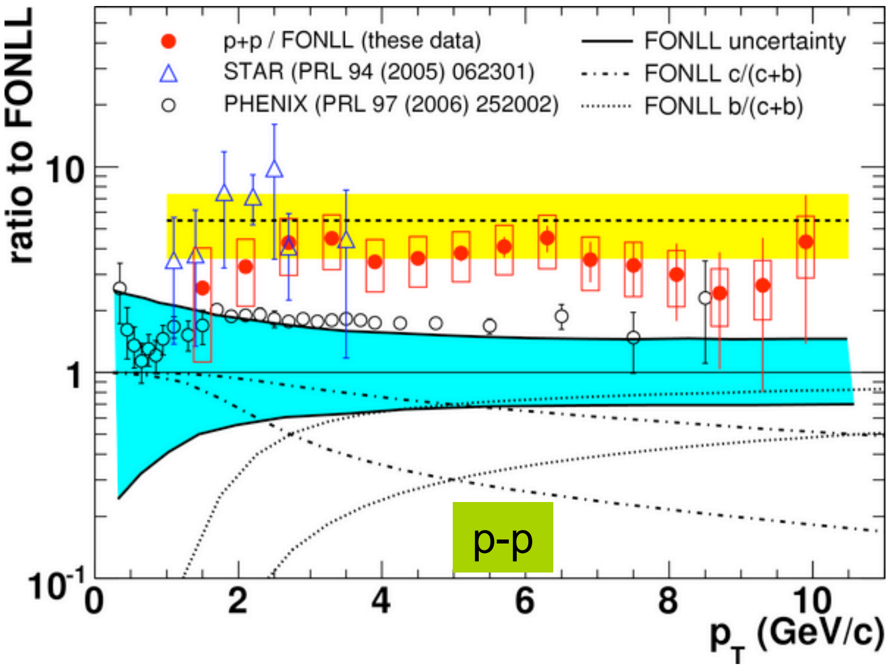
[A. Dion, QM 2009 talk]

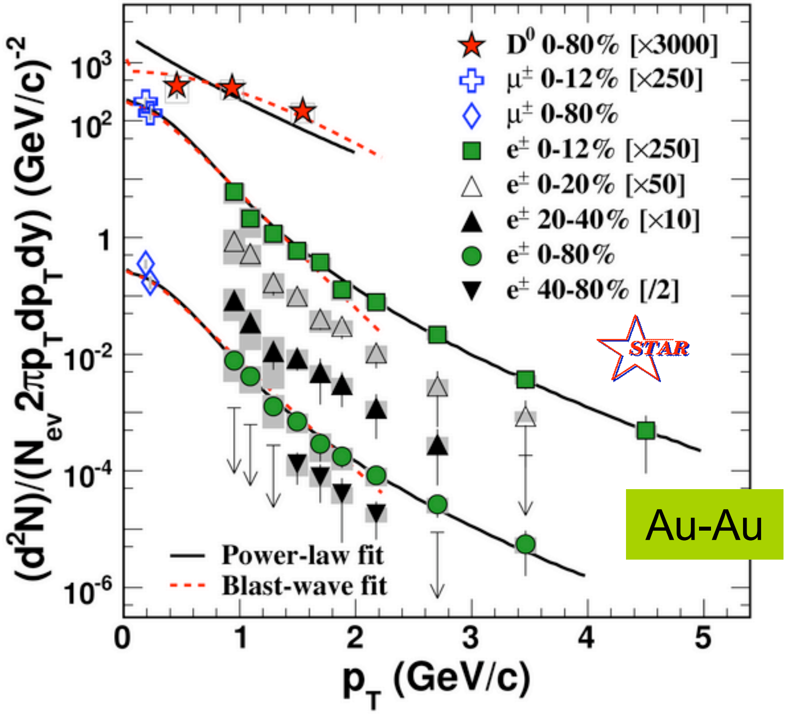
Heavy flavor p_t spectra comparison

- STAR total heavy flavor p_t spectra

[STAR, arXiv:0805.0364]

  - Constructed from single $e^\pm$, single $\mu^\pm$ and D mesons
  - The shape is well described by FONLL, but $\sigma(c\bar{c},\text{data})/\sigma(c\bar{c},\text{FONLL})=5.5\pm0.8(\text{stat})\pm1.7(\text{sys})$ in p-p coll.

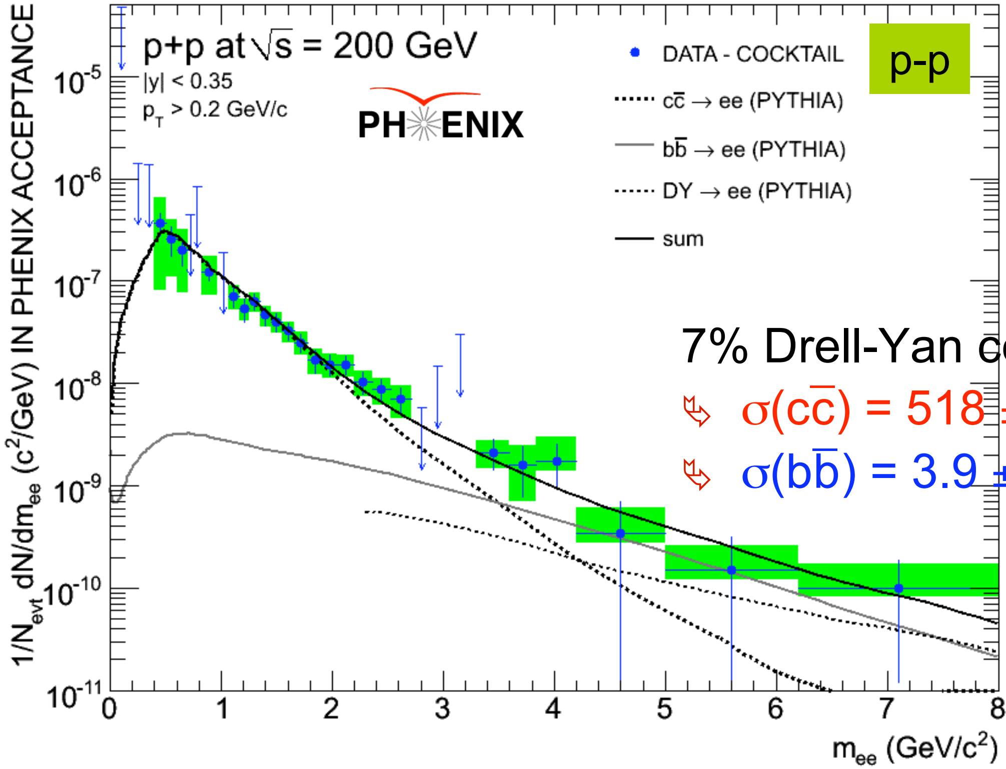


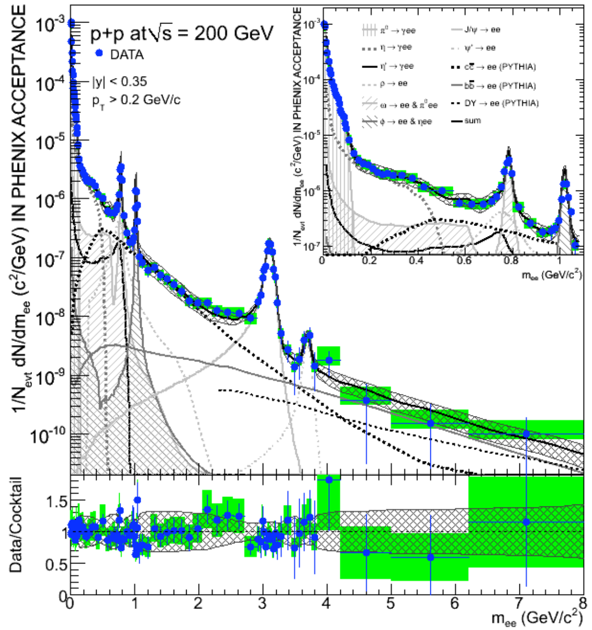


- Both STAR & PHENIX have multiple independent measurements.
- Their calculations are self-consistent,
- … but they differ by about a factor of 2 !

Dilepton invariant mass

- e^+e^- at $|y|<0.35$ in p-p coll. at 200 GeV
  - Subtract light meson decays
  - Remaining amount accounted by cocktail of charm, bottom and Drell-Yan decays.





7% Drell-Yan contribution subtracted

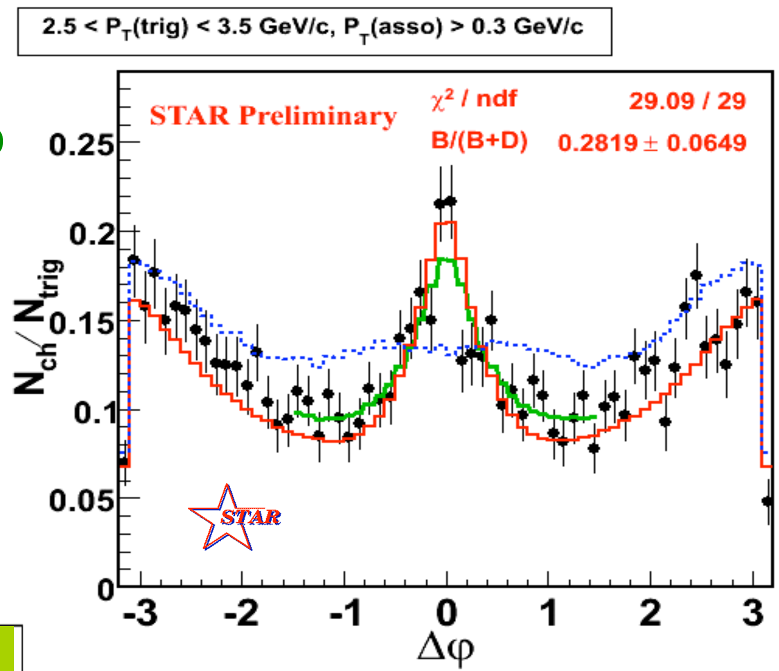
- $\sigma(c\bar{c}) = 518 \pm 47(stat) \pm 135(sys) \pm 190(model)\ \mu b$;
- $\sigma(b\bar{b}) = 3.9 \pm 2.5(stat)\ ^{+3}_{-2}(sys)\ \mu b$.

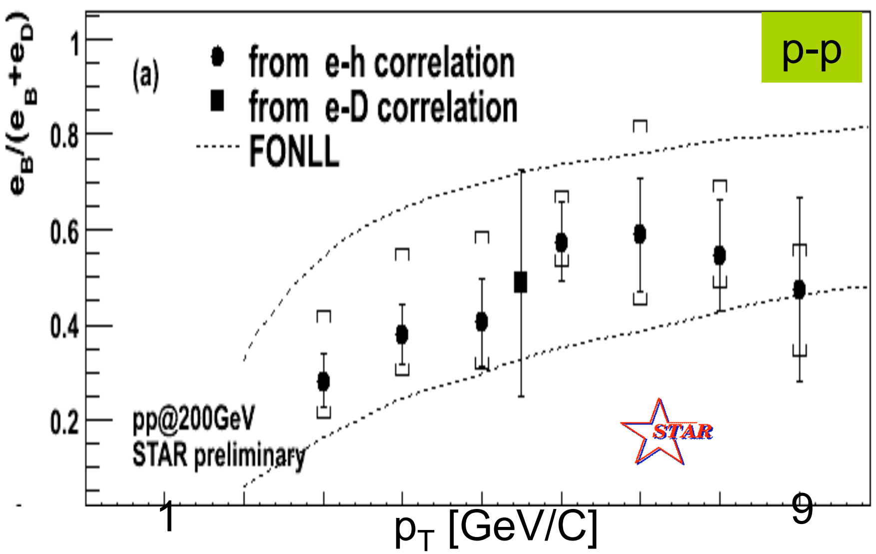
[PHENIX, P.L.B 670, 313 (2009)]

Two independent and self-consistent open charm cross section measurements consistent with FONLL, $\sigma(data)/\sigma(FONLL)$~2.0

Electron-hadron angular correlations

- B and D decays angular distributions differ.
- Electron to charged hadron (no PID) or D meson correlations
- Photonic electron contribution subtracted by neglecting all electrons associated to pairs with m_{ee} close to π^0, η Dalitz decays and γ-conversions.

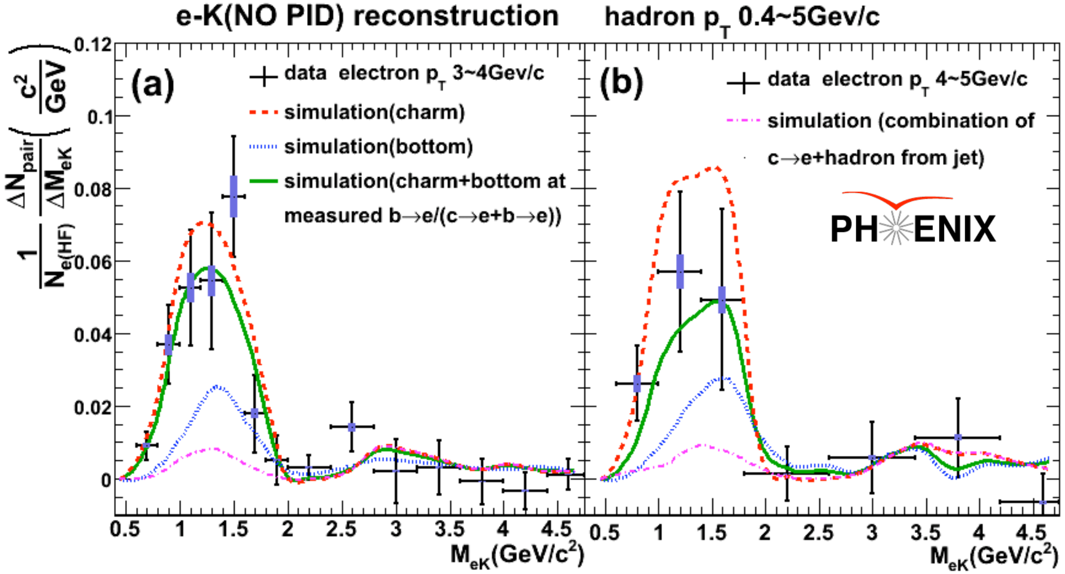


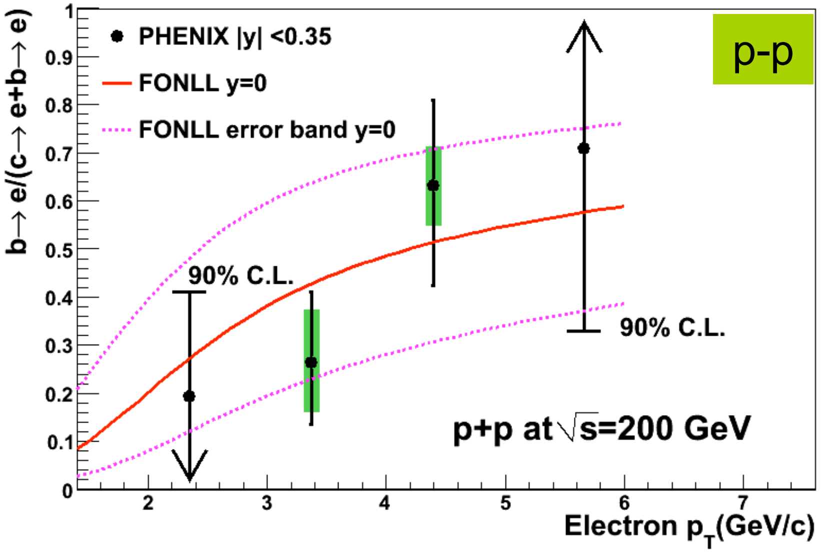


- Correlations compared to PYTHIA B & D predictions to extract B/(B+D) ratio per p_t bin
- Result compatible with FONLL

[STAR, arXiv: nucl-ex/0609034 (2006)]
[B.Biritz, QM 2009 talk]

Electron-K correlations

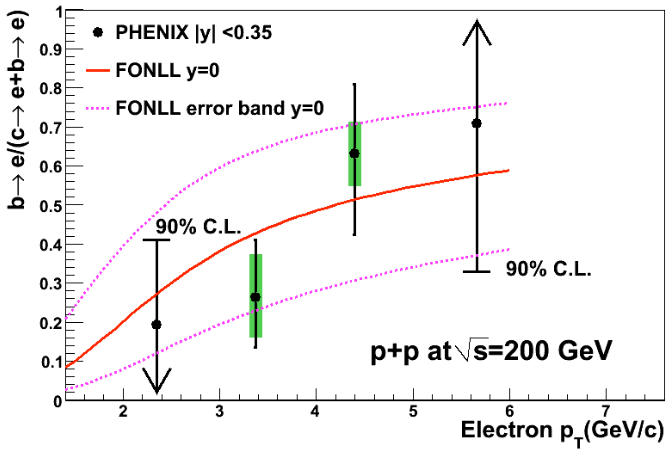




- Electron - K(no ID) invariant mass per electron is different for bottom and charm decays
- Compared to PYTHIA predictions for B & D decays to extract B/(B+D) ratio per p_t bin
- Result is compatible with FONLL prediction and STAR measurements.
- At p_t>5 GeV/c bottom contribution becomes significant !

[PHENIX, arXiv: 0903.4851 (2009)]
[Y.Morino, QM 2008 talk]
[STAR, arXiv: nucl-ex/0609034 (2006)]
[B.Biritz, QM 2009 talk]

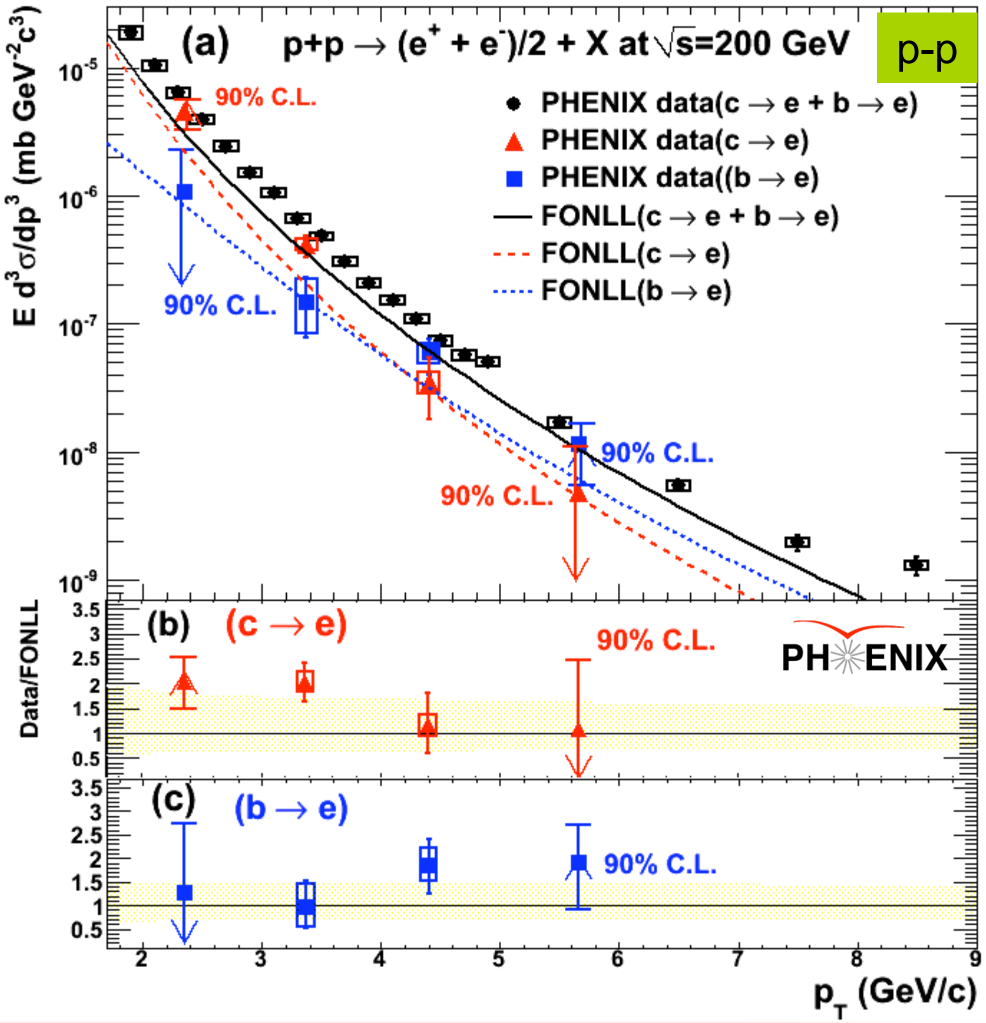
Beauty and charm decays pt spectra



Open heavy flavor electron p_t spectrum

$\oplus$

its B/(B+D) p_t dependence



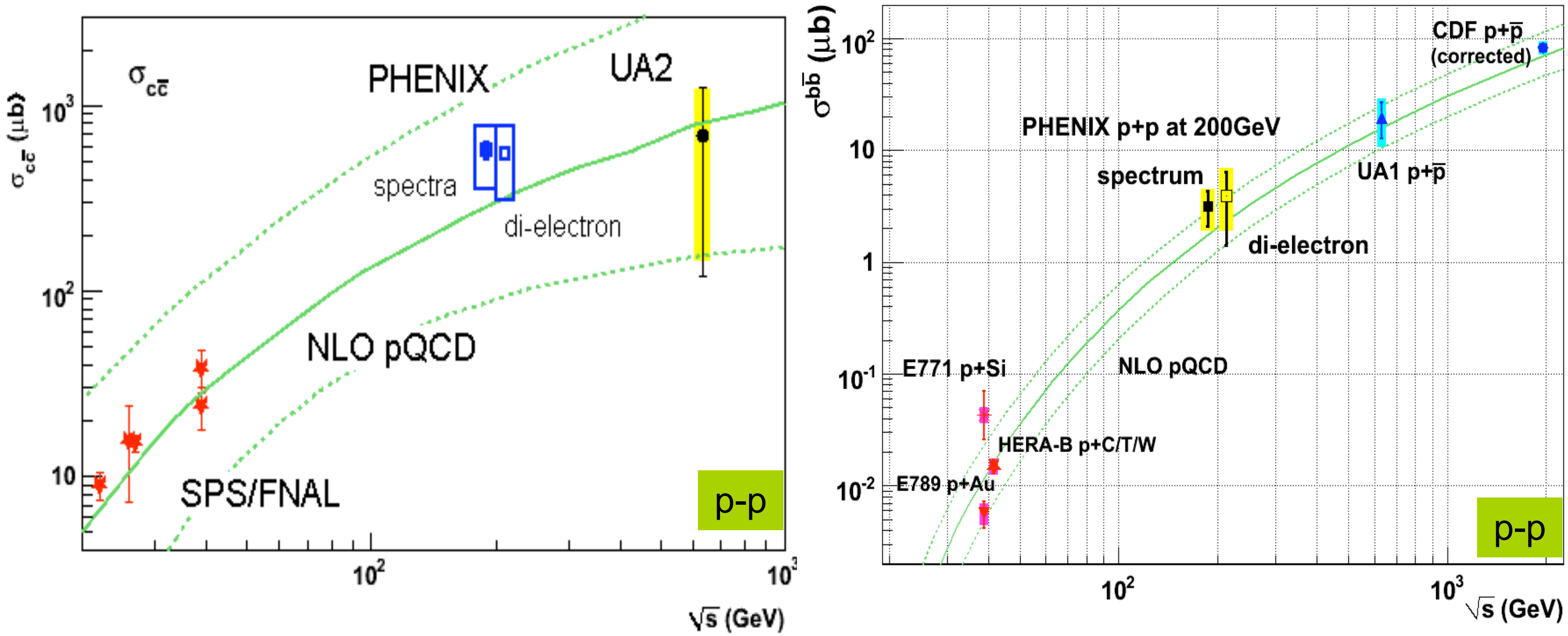
- Independent bottom and charm decays p_t spectra,
- …consistent with FONLL.

- Extrapolation to low p_t
  $\sigma(b\bar{b}) = 3.2\ ^{+1.2}_{-1.1}(\mathrm{stat})\ ^{+1.4}_{-1.3}(\mathrm{sys})\ \mu\mathrm{b}$.

[PHENIX, arXiv: 0903.4851 (2009)]
[Y.Morino, QM 2008 talk]

Charm and beauty cross sections

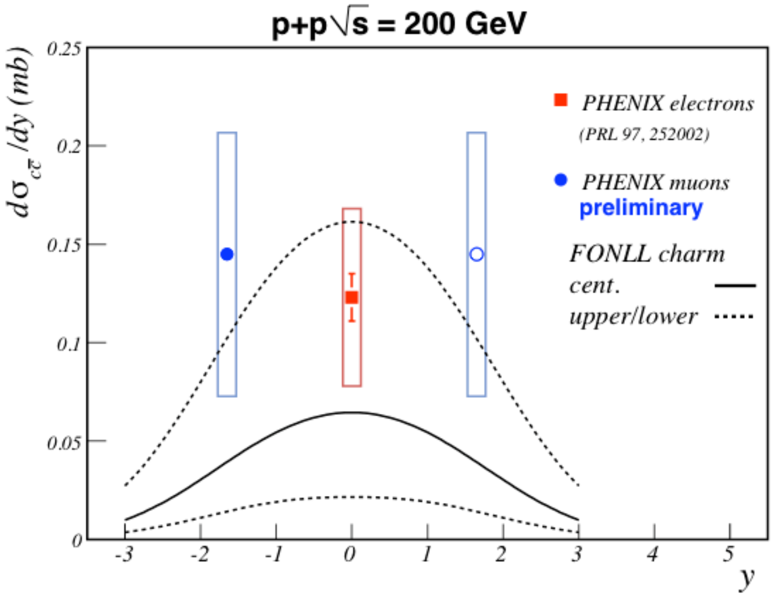
- Independent measurements of charm and bottom cross sections agree with each other and follow the FONLL energy dependence trend.

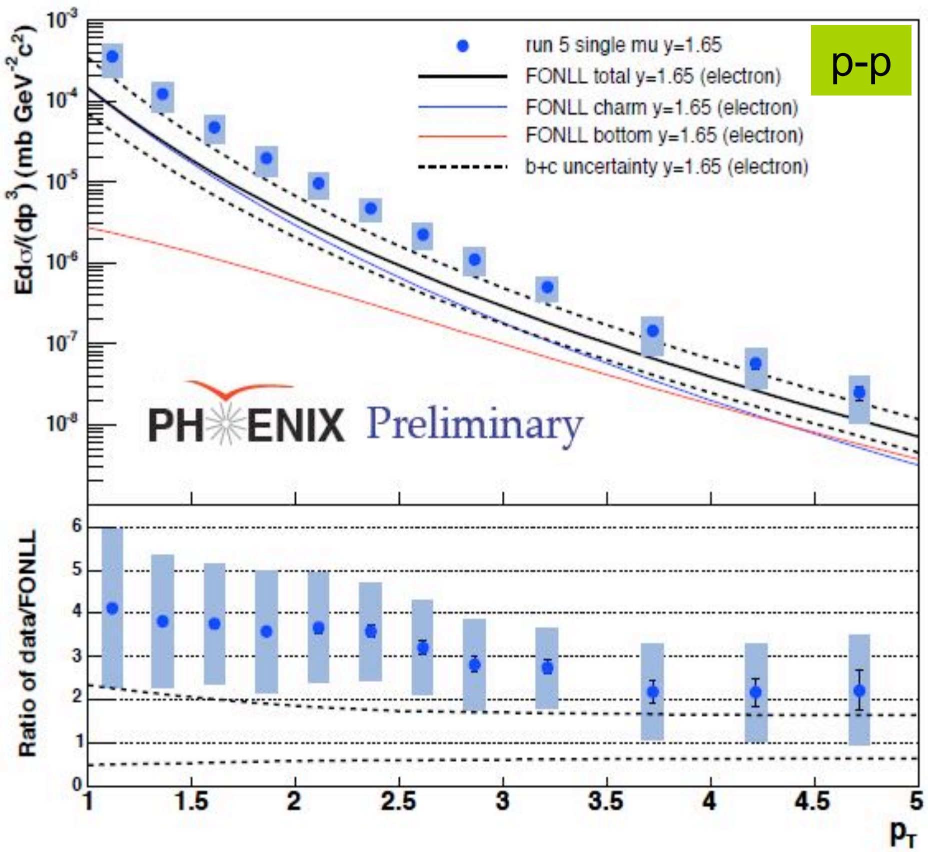


Open heavy flavor rapidity dependence

- Heavy flavor spectra is also measured at forward rapidity
  - Single μ spectra,
  - Vertex distribution & stopped hadrons to control background.

- $d\sigma/dy$ is consistent with FONLL within the uncertainties
- … but does not allow B & D separation



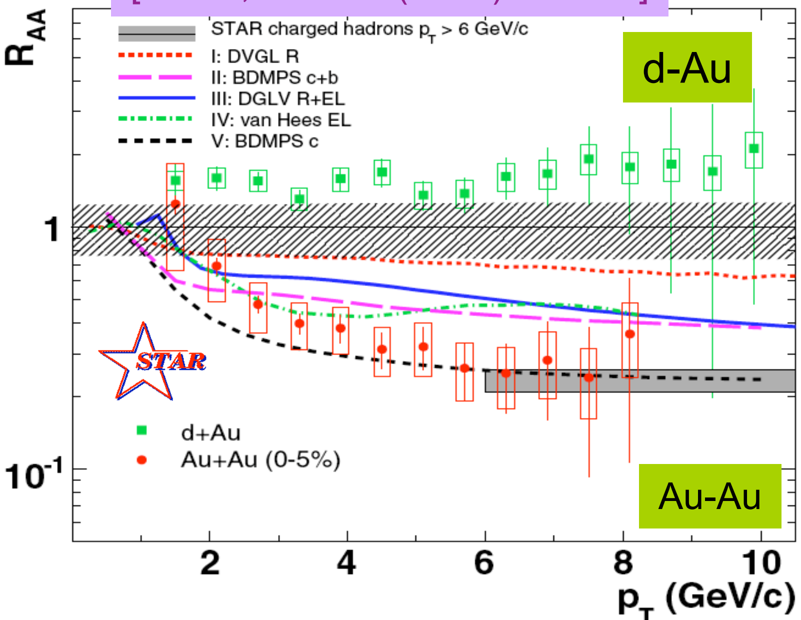


- Forward rapidity measurements in Cu-Cu are available though the uncertainties are large.

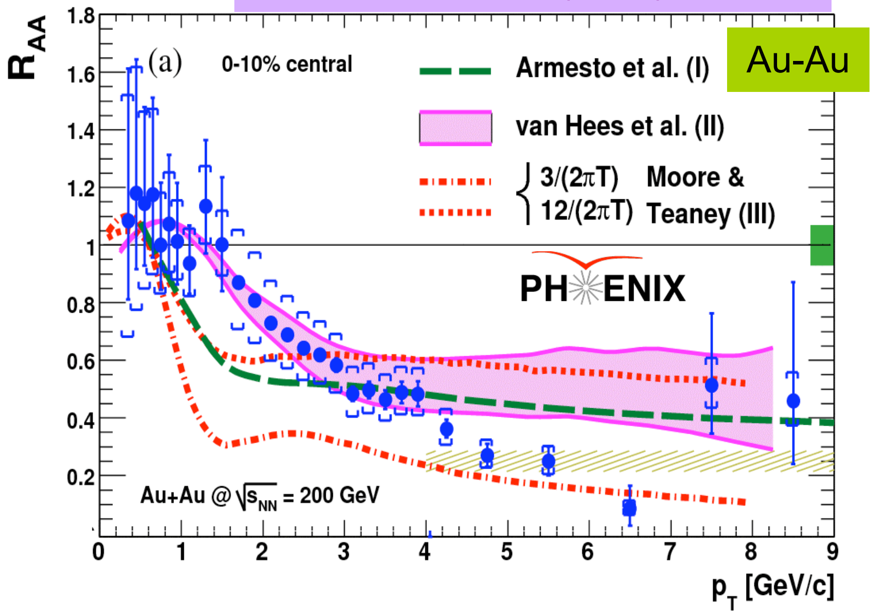
[D.Hornback, QM 2008 talk]
[I.Garishvili, QM 2009 poster]

Cold and hot nuclear matter influence

[STAR, PRL 98 (2007) 192301]



[PHENIX, PRL 98 (2007) 172301]

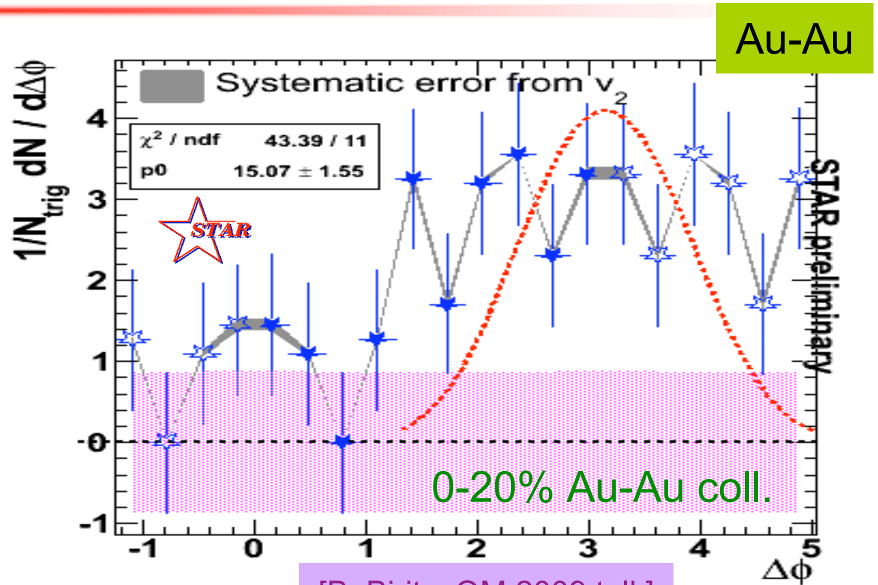


- There is no strong evidence of any cold-nuclear matter suppression (large uncertainties, $R_{dAu} \geq 1$)
  → need of more precise data
- Both experiments observe a strong suppression of heavy flavor decays in central Au-Au coll., of the same order than π^0 and hadron suppression
  … it persists up to high pt suggesting that both b & c loose energy !
- Tool to study the mechanisms of heavy quark energy loss… There is no unique interpretation yet !
- More precise measurements to come soon !

[c.f. W. Horowitz's talk]

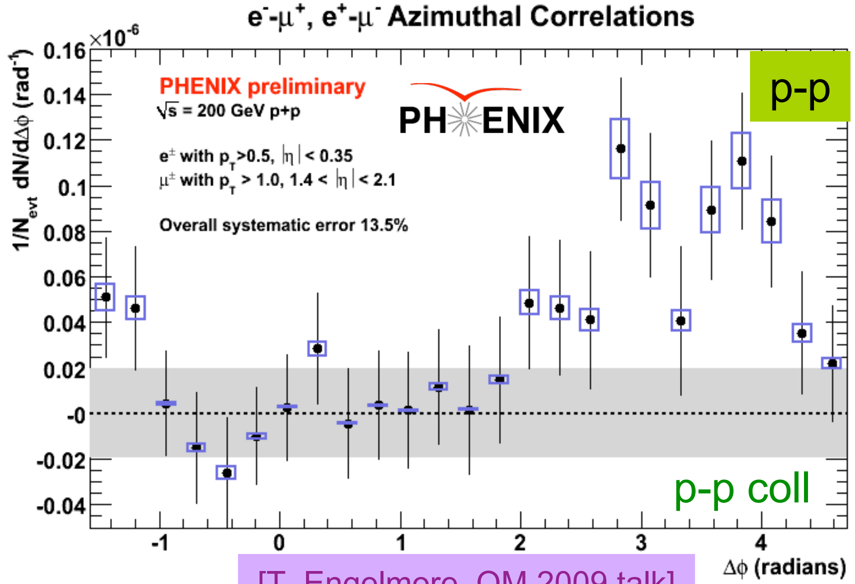
Promising probes…

- (e-hadron) angular correlations in Cu-Cu & Au-Au
  - May constrain charm and bottom decays behaviour in HI collisions,
  - Current uncertainties preclude any conclusion yet.



[B. Biritz, QM 2009 talk]

- (e-μ) angular correlations
  - Should allow to measure charm production cross-section in an intermediate y range,
  - Proof of principle in p-p coll.



[T. Engelmore, QM 2009 talk]

- Future vertex detectors
  - B-tagging purposes

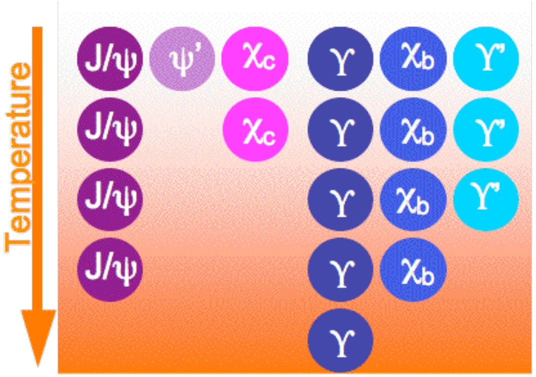
Highlights from beauty…

- Heavy quark decays p_t spectra has been measured at RHIC.
  - Its shape is consistent with FONLL,
  - but there are discrepancies on the production cross-section.
- B/(B+D) ratio vs lepton p_t measurement and indicates that for p_t>5GeV/c beauty decays contribution is significant.
- Charm and beauty production cross sections have been computed.
- Heavy quark nuclear R_{AuAu} suppression up to high p_t indicates that both charm and beauty quarks suffer in-medium energy loss

- … what seems to be missing:
  - STAR: σ(pp) and analysis with its reduced material run
  - PHENIX: d-Au & CuCu studies
  - Precise vertex measurements from both STAR and PHENIX


Doubly beautiful:
Bottomonia measurements...

Motivations



- Lattice QCD predicts a sequential melting of the different quarkonium states…

	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon'(2S)$	$\chi_b'(2P)$	$\Upsilon''(3S)$
M [GeV]	3.10	3.41	3.69	9.46	9.86	10.02	10.23	10.36
E_s^i [GeV]	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
T_d/T_c	2.1	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17

[c.f. A. Mocsy's talk]

At most central RHIC Au-Au collisions:

- lQCD expects all charmonia and bottomonia but Υ could melt.
- J/Ψ suppression is observed, but there is no unique interpretation yet
  - Are cold nuclear matter effects (CNM) understood ?
  - Are gluon saturation mechanisms at play ?
  - Are J/Ψ regenerated ?

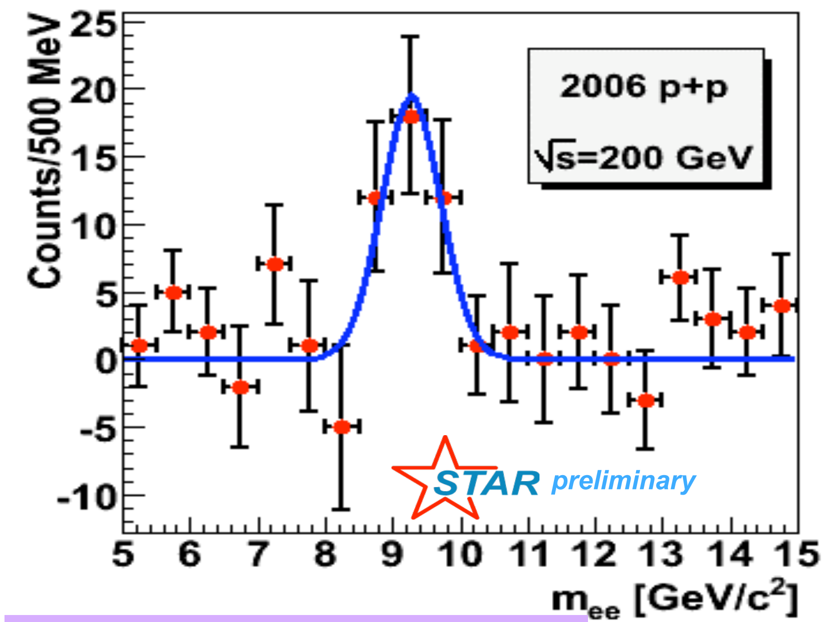
[c.f. Z. Tang's talk]

- The interest on Υ measurements is :
  - Production mechanisms better understood, CNM influence probably smaller
  - Probe of lQCD, regeneration is negligible, Υ(1S) probably survives
  - The challenge is their low cross-section (statistics)

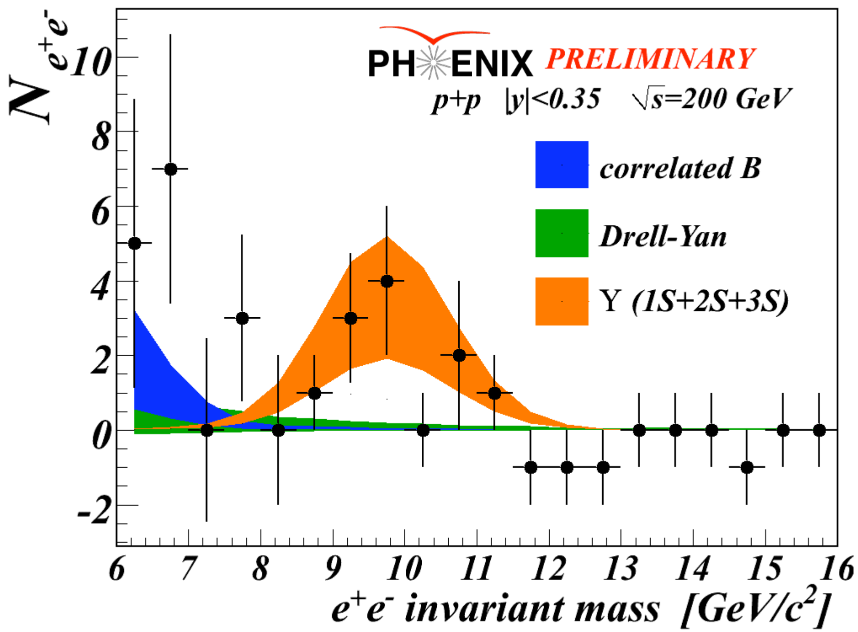
Upsilon states measurements in p-p

p-p

- Both experiments evidence ϒ production at mid-rapidity
- PHENIX
  - Limited statistics, raw e^+e^- yield $10.5^{+3.7}_{-3.6}$ (stat)
  - Studied it at forward rapidity too raw $\mu^+ \mu^-$ yield 27 ± 5 (stat)
- STAR has an ϒ-dedicated trigger ($e^\pm$ E>4GeV)
  - Larger statistics, raw e^+e^- yield 48 ±14 (stat)
  - Significant peak, >3σ measurement



[STAR Coll, J.Phys.G 34 (2007) S947]

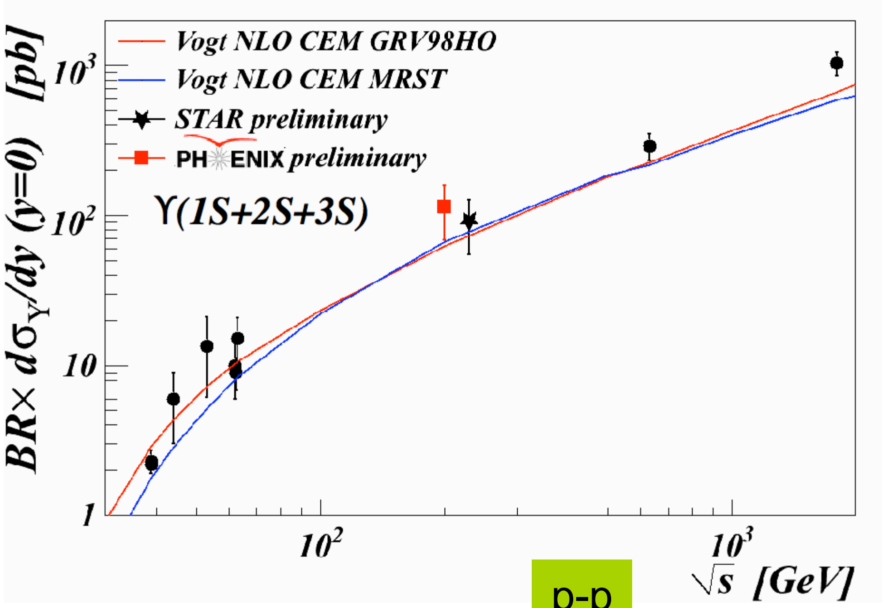


[C.Silva QM 2009 talk]

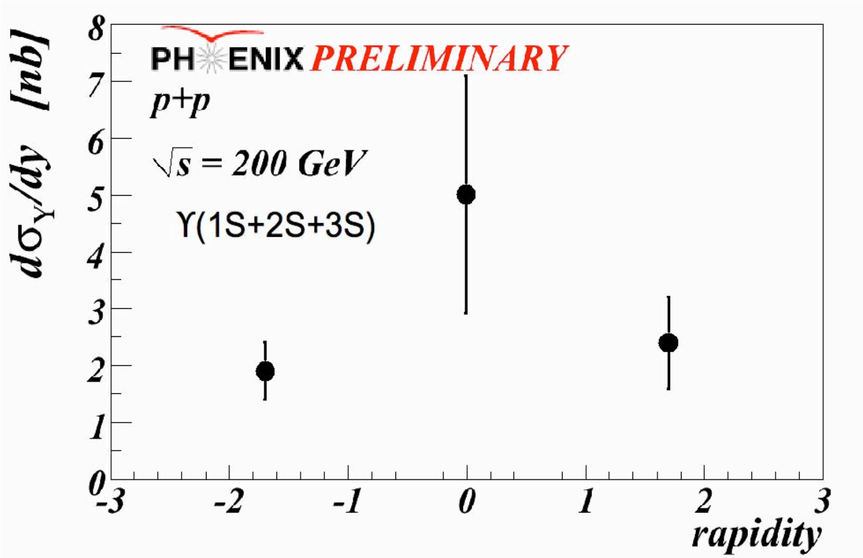
Their production at RHIC

- Expected continuum contribution under the Υ peak <10-15%
  - STAR,
    e^+e^- continuum not subtracted
    $Bd\sigma/dy|_{|y|=0} = 97 \pm 28(stat) \pm 22\ (sys)$ pb
  - PHENIX,
    e^+e^- continuum subtracted
    $Bd\sigma/dy|_{|y|<0.35} = 114^{+46}_{-45}$ pb
    $\mu^+\mu^-$ continuum not subtracted

- PHENIX and STAR measurements are in agreement and are consistent with pQCD calculations !

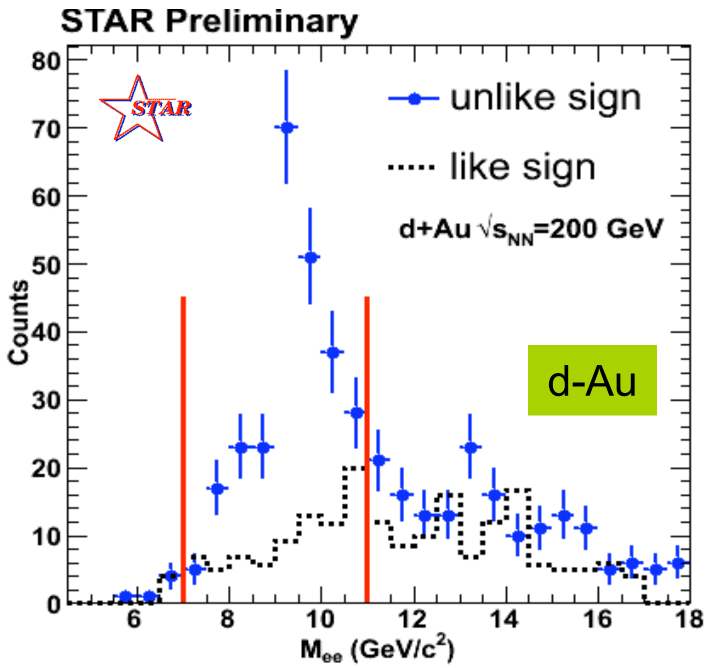


p-p



Cold nuclear matter effects

[H. Liu QM 2009 talk]

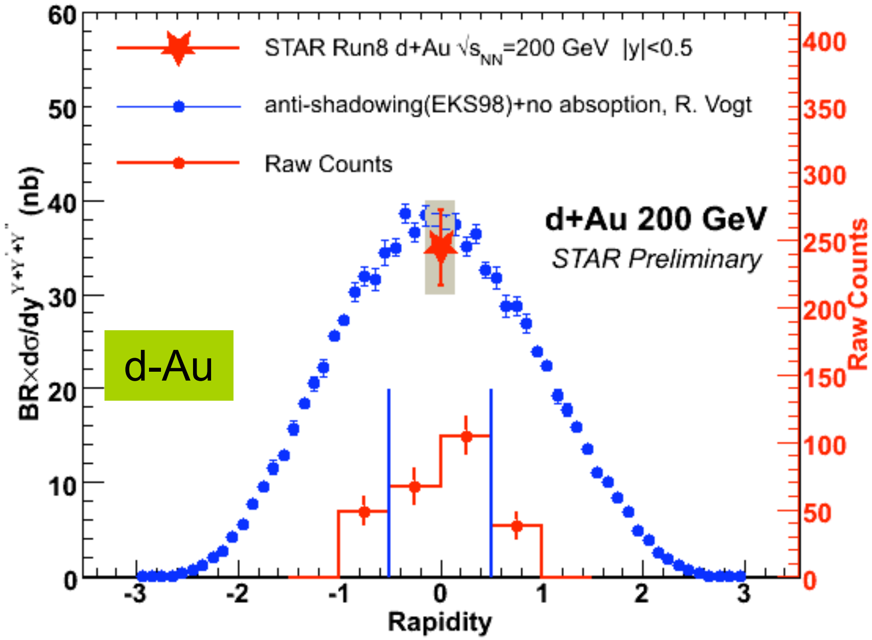


- $\Upsilon \rightarrow$e+e- invariant mass
  - Raw yield 172 ± 20
  - 8σ significance
- e$^+$e$^-$ continuum not subtracted
  Bdσ/dy$|_{|y|=0}$ = 35 ± 4 (stat) ± 5 (sys) nb.
- Compatible with calculation with EKS98 anti-shadowing.

- Together with p-p calculation:

$$\boxed{R_{dAu} = 0.98 \ \pm 0.32\ (\text{stat.}) \ \pm 0.28\ (\text{sys.})}$$

- $\Upsilon \rightarrow$e+e- in d-Au is consistent with Ncoll scaling
- There is no evidence for strong cold nuclear matter influence on Υ production



Hot nuclear matter effects

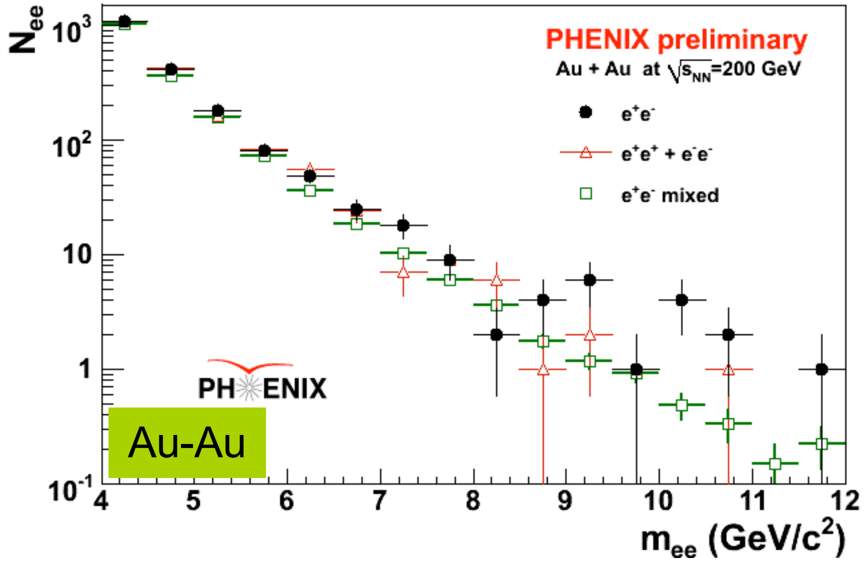
- STAR has evidence of Υ production in Au-Au coll. … waiting for its cross-section !

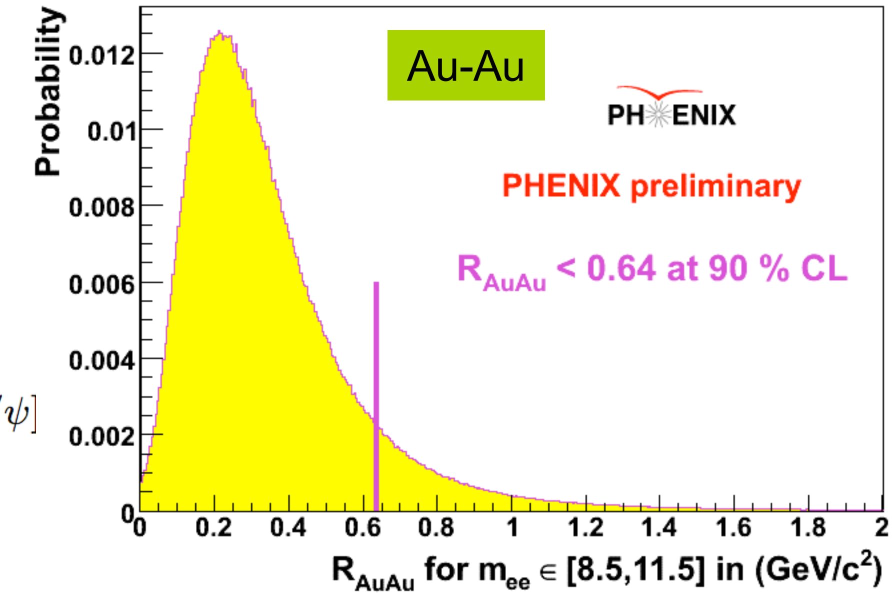
- PHENIX is able to reconstruct both J/Ψ & Υ with the same trigger configuration and analysis technique
  - High mass yield is small $N[8.5,11.5]=11.7^{+4.7}_{-4.6}$
  - But J/Ψ are abundant and serve as relative normalization
  - Continuum contribution under the Υ peak not subtracted yet
  - Upper-limit of the high mass signal on the Υ mass range

$$R_{AA}[8.5,11.5] \propto \frac{N[8.5,11.5]_{AA}/N[J/\psi]_{AA}}{N[8.5,11.5]_{pp}/N[J/\psi]_{pp}} \times R_{AA}[J/\psi]$$

- $R_{AuAu}[8.5,11.5]<0.64$ at 90%CL

[E.T. Atomssa talk + ZCdV poster, QM 2009]





Playing to interpret data

R_{AuAu}[8.5,11.5]<0.64 at 90%CL

High mass counts R_{AuAu} is suppressed, but why ?

I. Tevatron measurements indicate that ~ 50% Υ are from χ_b feed-down for p_t>8GeV/c (should be lower for smaller p_t). [CDF Coll. PRL84 (2000) 2094

II. Cold nuclear matter (shadowing, absorption), STAR: $R_{dA}\,[\Upsilon,\Upsilon',\Upsilon''] = 0.98 \pm 0.32 \pm 0.28$

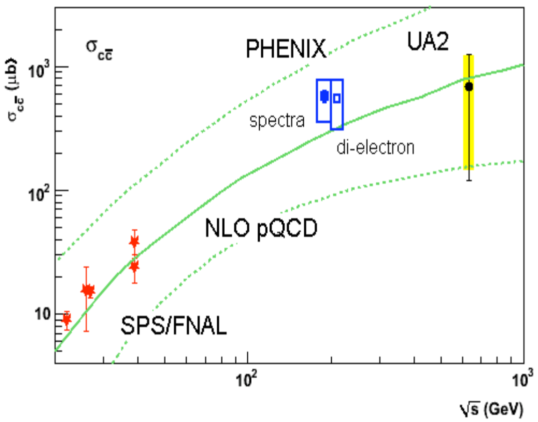
III. Only ~73% of Upsilons are ground states, which lQCD predicts not to melt, while the excited states could : $R_{AA} \sim 0.73$

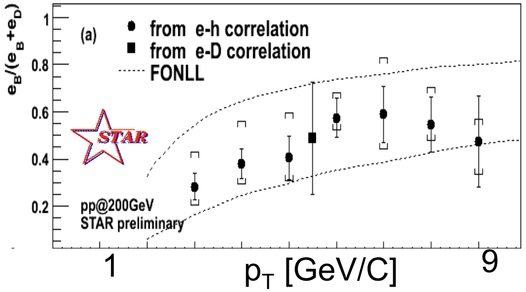
IV. Continuum (Drell-Yan,$B\bar{B}$) contributions may vary from p-p to Au-Au

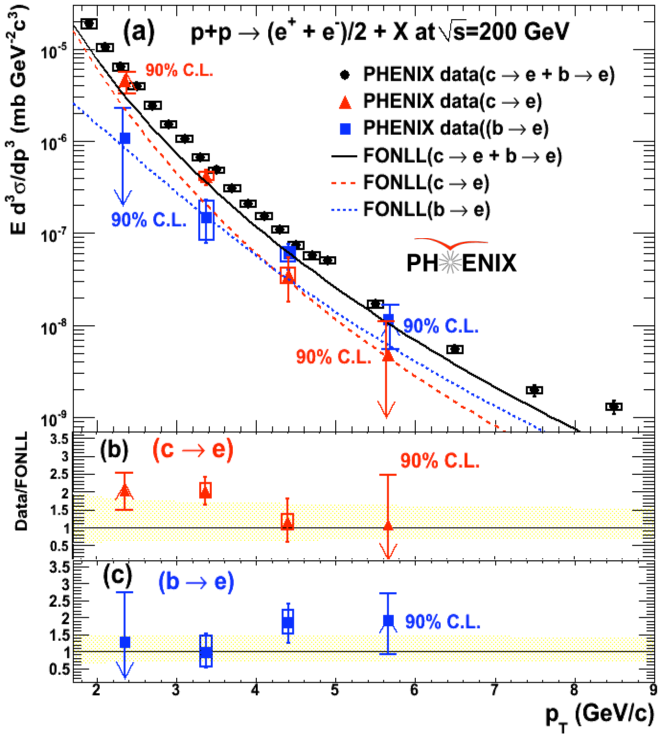
- Rough estimates
  - "Conservative": STAR-CNM × lQCD ~ 0.7
  - "Extreme": consider feed-down contribution is still 50% at low p_t
    STAR-CNM × lQCD × feed-down ~ 0.4
- But indeed… we do not know what is up yet !
- Need more statistics in all p-p, d-Au & Au-Au coll. to be able to derive any strong conclusion.
- Theoretical predictions would be most welcome !

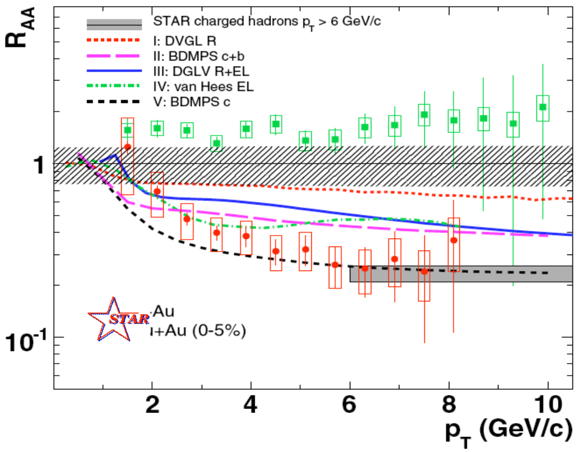

To end up...

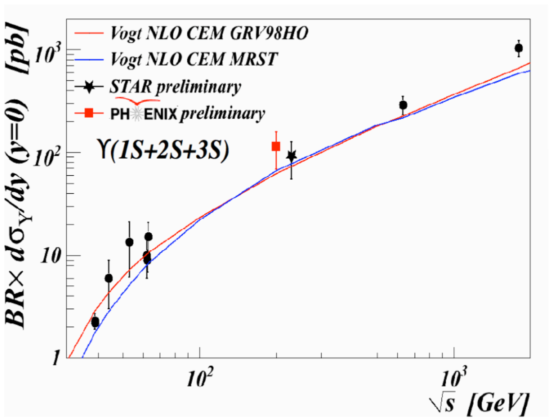
Plots Summary

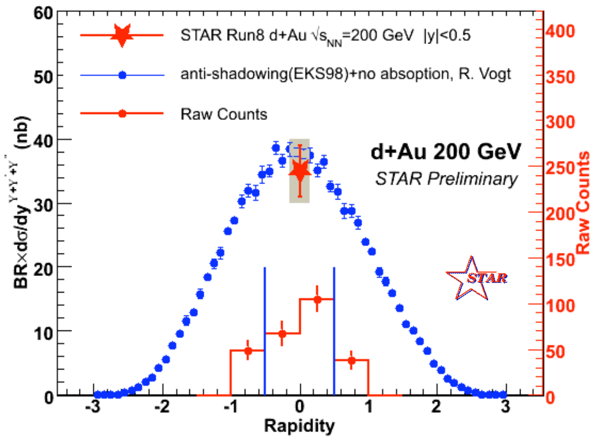


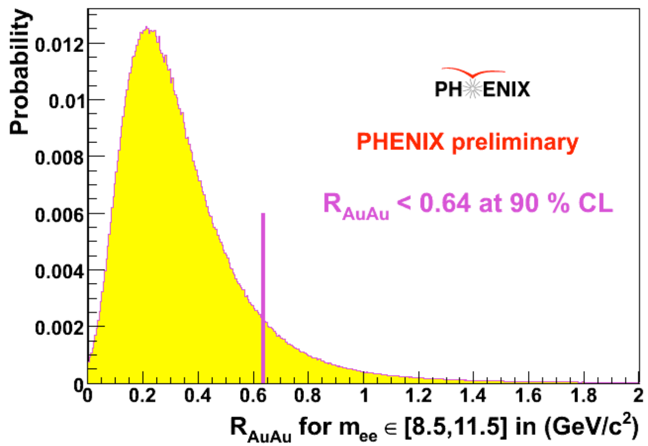












Would be great to get more statistics !

Many thanks to the organizers for the invitation.
Special acknowledgements to
H. Liu & R. Granier de Cassagnac
for interesting discussions.